RETRIEVAL OF CO FROM SCIAMACHY ONBOARD ENVISAT

C. Frankenberg, U. Platt, and T. Wagner

Institut für Umweltphysik, 69120 Heidelberg, Germany
e-mail: christian.frankenberg@iup.uni-heidelberg.de

ABSTRACT

SCIAMACHY onboard the environmental research satellite ENVISAT is a UV/visible/near-infrared grating spectrometer providing 3 near infrared channels covering wavelengths from 1-1.75μm, 1.94-2.04μm and 2.26-2.38μm with moderate spectral resolution (0.22-1.5nm) (Bovensmann et al. 1999). Among the absorbers in these regions are the greenhouse gases CO_2, CH_4, N_2O and H_2O as well as CO. A modified DOAS algorithm basing on optimal estimation (IMAP-DOAS) has been developed at the University of Heidelberg to account for the peculiarities of the near infrared spectral region (Frankenberg et al. 2004). Especially for the proper retrieval of CO in channel 8 of SCIAMACHY, the calibration of the raw spectra with respect to dark current issues and nonlinearity were analysed in detail and substantially improved. This paper focusses on first results of the CO retrieval where some very interesting sources like biomass burning events can be clearly identified.

Key words: SCIAMACHY; CO; DOAS; near infrared.

1. INTRODUCTION

CO is one of the most important pollutants in the troposphere and also CO itself is not a greenhouse gas, it has an indirect effect on the climate by being a sink for the OH radical, thus leading to longer lifetime of direct greenhouse gases such as CH_4 (IPCC 2001). Since CO has weak absorption lines in the near infrared spectral region which is covered by SCIAMACHY, its integrated concentration along the light path (called slant column density, SCD) can be inferred from the ratio of nadir radiance and solar irradiance spectra using the DOAS method (Platt 1994). The near infrared spectral region has the advantage that most of the measured light is reflected from the earth surface and not scattered within the atmosphere. Thus, SCIAMACHY has a high sensitivity to the lower layers of the atmosphere which is of special importance for human health issues and an improvement to infrared sounders.

However, the near infrared spectral region shows some peculiarities (sensitivity temperature and pressure and spectrally non-resolved strong and narrow absorption lines) that render classical DOAS algorithms useless. To account for these problems, a new iterative maximum a posteriori DOAS (*IMAP*-DOAS) approach has been developed in Heidelberg. Other research groups, like Buchwitz et al. (2000) or Schrijver (2004), also developed modified algorithms for the near infrared spectral region and some preliminary results are shown by Buchwitz et al. (2004) and Gloudemans et al. (2004).

In addition to these improvements of the classical DOAS algorithm, instrumental problems of higher dark currents of the near infrared detectors are an important issue and have to be analysed and corrected in detail.

2. THE SCIAMACHY INSTRUMENT AND DATA ANALYSIS

SCIAMACHY onboard the European Space Agencies environmental research satellite ENVISAT is a grating spectrometer consisting of 8 channels measuring in the ultraviolet, visible and near infrared wavelength region (240nm–2380nm). The satellite operates in a near polar, sun-synchronous orbit at an altitude of 800km and a local equator crossing time at approximately 10:00 am. The typical ground pixel size of SCIAMACHY is 30km (along track) times 60km (across track), thus being a substantial improvement to the large footprint of the predecessor instrument GOME onboard ERS-2.

SCIAMACHY is designed to measure sunlight that is either transmitted, reflected or scattered by the earth atmosphere or surface. For this purpose it has 3 viewing geometries, Nadir, Limb and Occultation. This work focusses only on Nadir spectra because they yield detailed information on the tropospheric CO abundance. We discuss instrument calibration issues, the development of a new algorithm and results of the CO retrieval.

2.1. IMAP-DOAS algorithm

The modified *iterative maximum a posteriori* -DOAS (*IMAP*-DOAS) algorithm is based on optimal estimation theory introduced to the remote sensing community by

Rodgers (1976). This method directly iterates the vertical column densities of the absorbers of interest until the expected total optical density fits the measurement. It accounts for nonlinearities due to strong absorptions, sensitivity of the measurement of strong absorbers to pressure and temperature changes in the atmospheric profile. This algorithm reduces the systematic biases that would occur in classical algorithms. It is most suitable for the near infrared spectral region where the absorptions are often strong, temperature dependent and not fully resolved by the spectrometer. A detailed description of the algorithm can be found in Frankenberg et al. (2004)

2.2. Dark current and nonlinearity

The near infrared channels exhibit a substantially higher dark current than the UV/Vis channels of SCIAMACHY. In addition to this complication, the leakage current (the time dependent part of the dark current) and the fixed pattern noise are not a smooth function but show strong variations over the whole detector array. Due to the variable ice deposition on the detectors, the dark current and the slit function show even a time dependent behaviour (Kleipool 2004). Thus, a simple correction is not possible and the operational correction algorithms have not yet solved the problem.

A first correction scheme has been implemented in the current *IMAP*-DOAS algorithm using daily raw readouts of the dark current to correct the raw spectra with the respective pixel exposure times (as initially proposed by the instrument PI J. Burrows, see technote by Kleipool (2003a)). Furthermore, the standard deviations of the daily dark current readouts are used in the algorithm to generate a daily dead/bad pixel mask and weight the available pixels according to their dark current stability. Since the dark current can also vary over the orbit (Kleipool 2004), a first order dark current offset correction has been implemented as fit factor in our algorithm. These modifications have substantially improved the retrieval in channel 8.

In addition to these complications, the detectors exhibit a nonlinearity (Kleipool 2003b) which has not yet been in the operational level1b-level1c processor. The proposed correction by Kleipool (2003b) which treats even and odd detector pixels separately has been implemented in the correction scheme.

2.3. Spectral fitting

For the retrieval of CO, a fit window in channel 8 between 2324 and 2335 nm was chosen. CO is a relatively weak absorber whose absorption lines are superposed by strong absorptions by CH_4 and H_2O. The root mean square (RMS) of the (not-weighted) residual of the fit in this wavelength range is typically about 0.9% (see Fig. 2). Considering this variance, the statistical errors in the CO column are about $3{\cdot}10^{17}\mathsf{molec/cm^2}$. Using only fits where the root mean square of the residual is below 1.7% and the statistical error of the CO vertical column density is below 30%, all outliers in the retrievals are masked out. These results can then be used for the analysis of the global distribution and variations of CO vertical column densities as will be shown later.

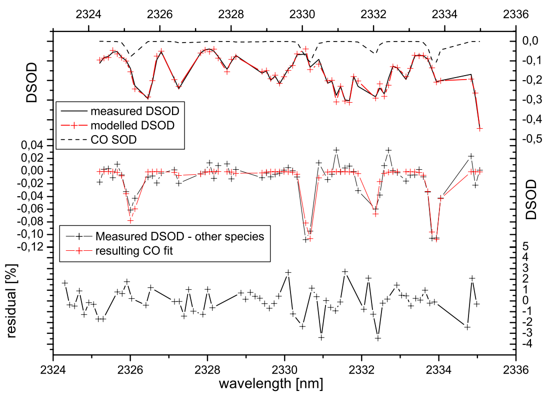

Figure 1. Example of a CO fit with relatively strong CO absorptions ($VCD \approx 8 \cdot 10^{18}\mathsf{molec/cm^2}$). The upper panel shows the differential slant optical density of all absorber (CH_4, H_2O and CO) as well as CO separated. The middle panel then shows the measured slant optical density minus the slant optical density of CH_4 and H_2O in order to see the absorption structures of CO. The lower panel shows the residual of the fit. For this fit not all of the improvements mentioned in Sec. 2.2 have been applied.

3. RESULTS

The aim of the CO retrieval is to detect global patterns and variations in the total column abundance of CO. Although the highest mixing ratios are expected in the boundary layer which is sometimes shielded from satellite observations by clouds, a substantial amount of CO can also be present above the clouds. Thus, all pixels have been taken into account for the analysis and cloud-covered pixels have not been masked out.

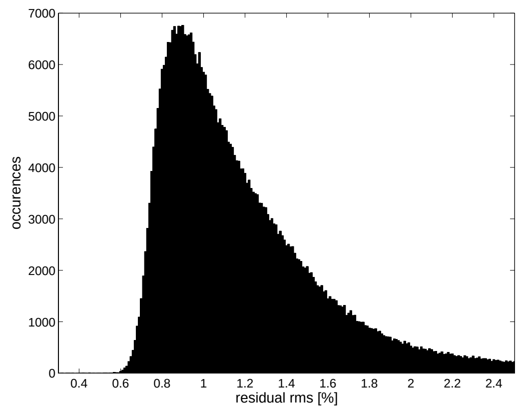

Figure 2. Histogram of the RMS of the fit residual for the CO retrieval in channel 8 during July 2004. Outliers exhibit a substantial higher RMS than 2% and can thus be easily discarded from further analysis.

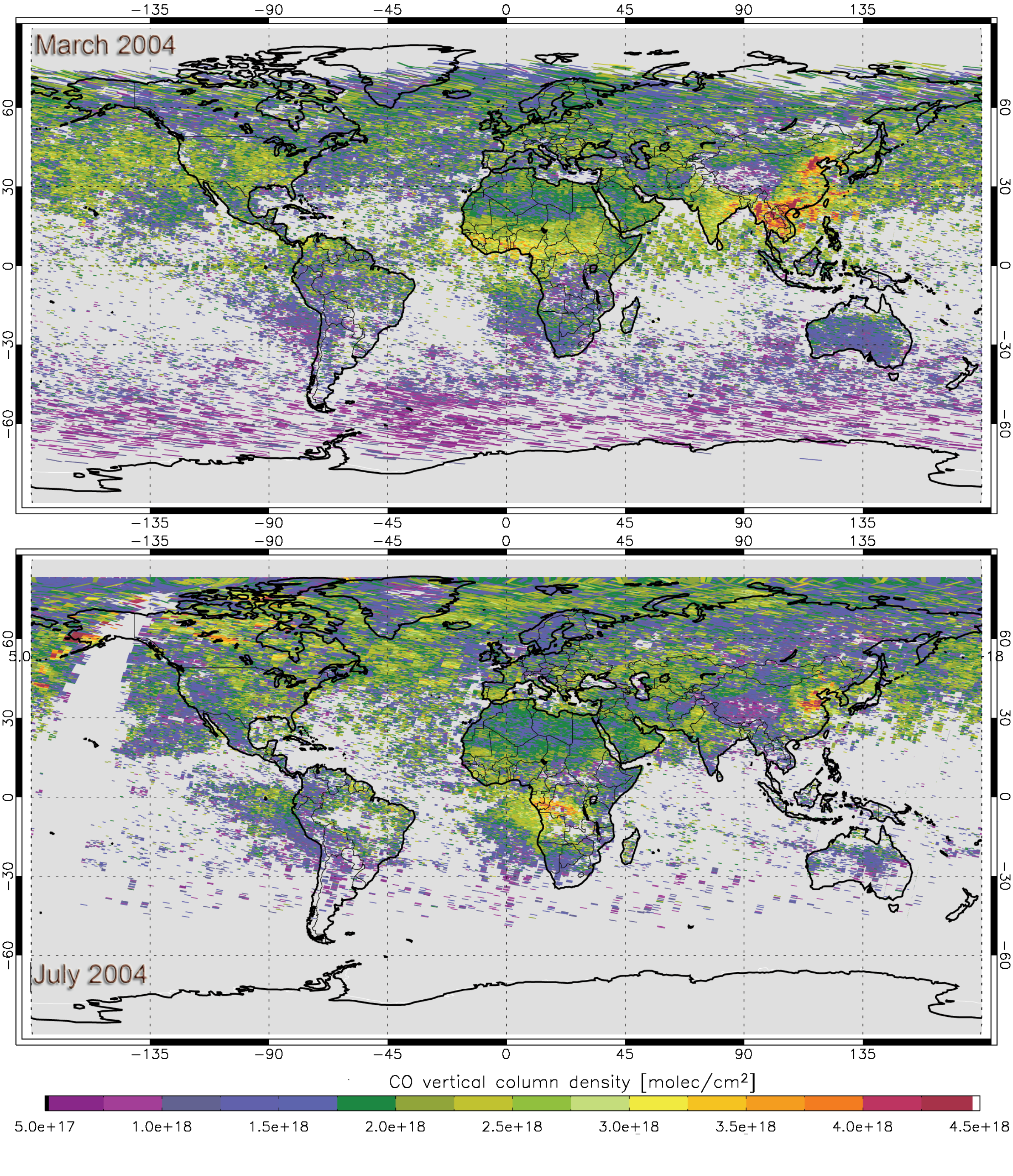

Figure 3. Maximum VCD's of CO *in March (upper panel) and July (lower panel) 2004. Shown are all values of the* CO *retrieval with a statistical error below 30% and a residual RMS below 1.7%. No cloud masking has been applied but only the highest values of* CO *in the respective regions are depicted (lower values are overlapped by pixels with a higher VCD)*

.

However, in order to account for clouds and other processes that might diminish the retrieved total column, monthly pictures of CO are depicted such that pixels (meeting the fit criteria described in Sec. 2.3) with higher VCD's are displayed above pixels with lower VCD's. Thus, the patterns of the maximum CO abundance within a certain time period can be depicted.

3.1. Monthly maps of CO

Monthly maps created as described before are a useful method to show the general patterns of CO abundance. Figure 3 depicts the maximum CO abudance in March and July 2004. In March, we can clearly identify strongly enhanced vertical columns in the Asian region around Bejing in China, in Thailand and India with values of up to 6.5 molec/cm^2. Furthermore, there is a region with substantial enhancements in Africa at about 10° north. Especially this region in Africa and the region in Thailand do not show enhanced columns in July 2004. In Africa, the biomass burning region is located further south, at about -10° latitude during this period. Also the region around Thailand does not show any strong biomass burning events in July 2004.

Only the region in China does not exhibit any such a strong difference between these months.

3.2. Seasonal variations of biomass burning

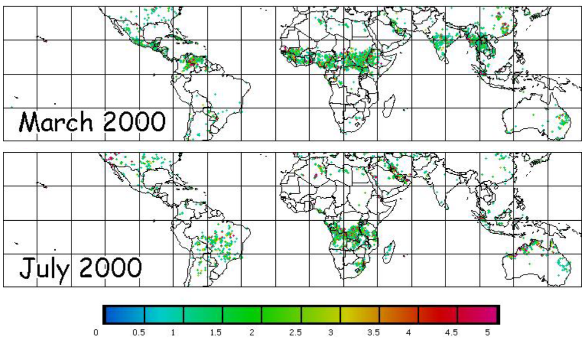

Figure 4. Example of a typical distribution of fires in March and July. Displayed are fire counts per pixel measured by the ATSR instrument onboard ERS-2. Although the data is from the year 2000, the general seasonal pattern of the fire distributions similar in each year and varies often only in magnitude.

In order to verify the assumption that most of the CO originates from biomass burning, an independent source of fire occurrences is necessary. The seasonal variations of the global distribution of biomass burning events can be well observed by the Along Track Scanning Radiometer (ATSR) onboard the European Research satellite ERS-2. Figure 4 shows fire counts made by ATSR in March and July 2000 which matches very well with the CO measurements in March and July 2004. Thus, the regions with enhanced CO columns in Africa, India and Thailand can be clearly attributed to fires.

Only the region around Bejing in China cannot be explained by biomass burning and do not show strong differences between March and July, indicating that the high abundance might be due to industrial activities. In addition to a typical fire distribution, enhanced CO abundance can be observed in July 2004 in Alaska due to strong biomass burning events.

4. CONCLUSIONS AND OUTLOOK

We have seen that SCIAMACHY enables global measurements of CO with high sensitivity in the boundary layer. Although the calibration of the spectra and the slit function pose some serious problems that have yet to be perfected, first results are very encouraging and prove that SCIAMACHY is able to detect CO globally with sufficient accuracy. Not only CO emitted by biomass burning events can be clearly observed by SCIAMACHY, but also industrial activities like in China. Thus, it provides important information on tropospheric chemistry issues.

More efforts in the calibration of the spectra and diminishing ice deposition on the detectors will further improve the fit quality.

ACKNOWLEDGMENTS

The authors wish to thank all people involved in the SCIAMACHY and ENVISAT mission, especially ESA/ESTEC, DLR, SRON, KNMI and of course the IUP Bremen team of J.P. Burrows without whom SCIAMACHY would not have been possible.

REFERENCES

Bovensmann, H., Burrows, J. P., Buchwitz, M., et al. 1999, J. Atmos. Sci., 56, 127

Buchwitz, M., Beek, R., Bramstedt, K., et al. 2004, Atmos. Chem. Phys. Discuss., 4, 2805

Buchwitz, M., Rozanov, V., & Burrows, J. 2000, J. Geophys. Res., 105, 15231

Frankenberg, C., Platt, U., & Wagner, T. 2004, Atmos. Chem. Phys. Discuss., submitted

Gloudemans, A., Schrijver, H., Straume, A., et al. 2004, in Proceedings ACVE2, 3-7 May, Frascati, Italy, Vol. 5235, Remote Sensing of Clouds and the Atmosphere VIII, submitted

IPCC. 2001, Climate Change 2001: The Scientific Basis, Summary for Policy Makers, iPCC (Intergovernmental Panel on Climate Change) Third Assessment Report, (available at: `http://www.ipcc.ch/`)

Kleipool, Q. 2003a, Algorithm Specification for Dark Signal Determination, Tech. rep. SRON-SCIA-PhE-RP-009, SRON

Kleipool, Q. 2003b, Recalculation of OPTEC5 Non-Linearity. Report containing the NL correction to be implemented in the data processor, Tech. rep. SRON-SCIA-PhE-RP-013, SRON

Kleipool, Q. 2004, SCIAMACHY: Orbital Variation of dark signal, Tech. rep. SRON-SCIA-PhE-RP-18, SRON

Platt, U. 1994, Differential optical absorption spectroscopy (DOAS), in Air Monitoring by Spectroscopic Techniques, ed. M. W. Sigrist (New York: John Wiley)

Rodgers, C. 1976, Rev. Geophys. Space Phys., 14, 609

Schrijver, H. 2004, in Proc. ESAMS, European Symposium on Atmospheric Measurements from Space, Vol. 5235, ESA WPP-161 1, Estec, Nordwijk, The netherlands, 285–294, submitted